# AFCI Semi Annual Review

## AFCI ANL Physics Activities

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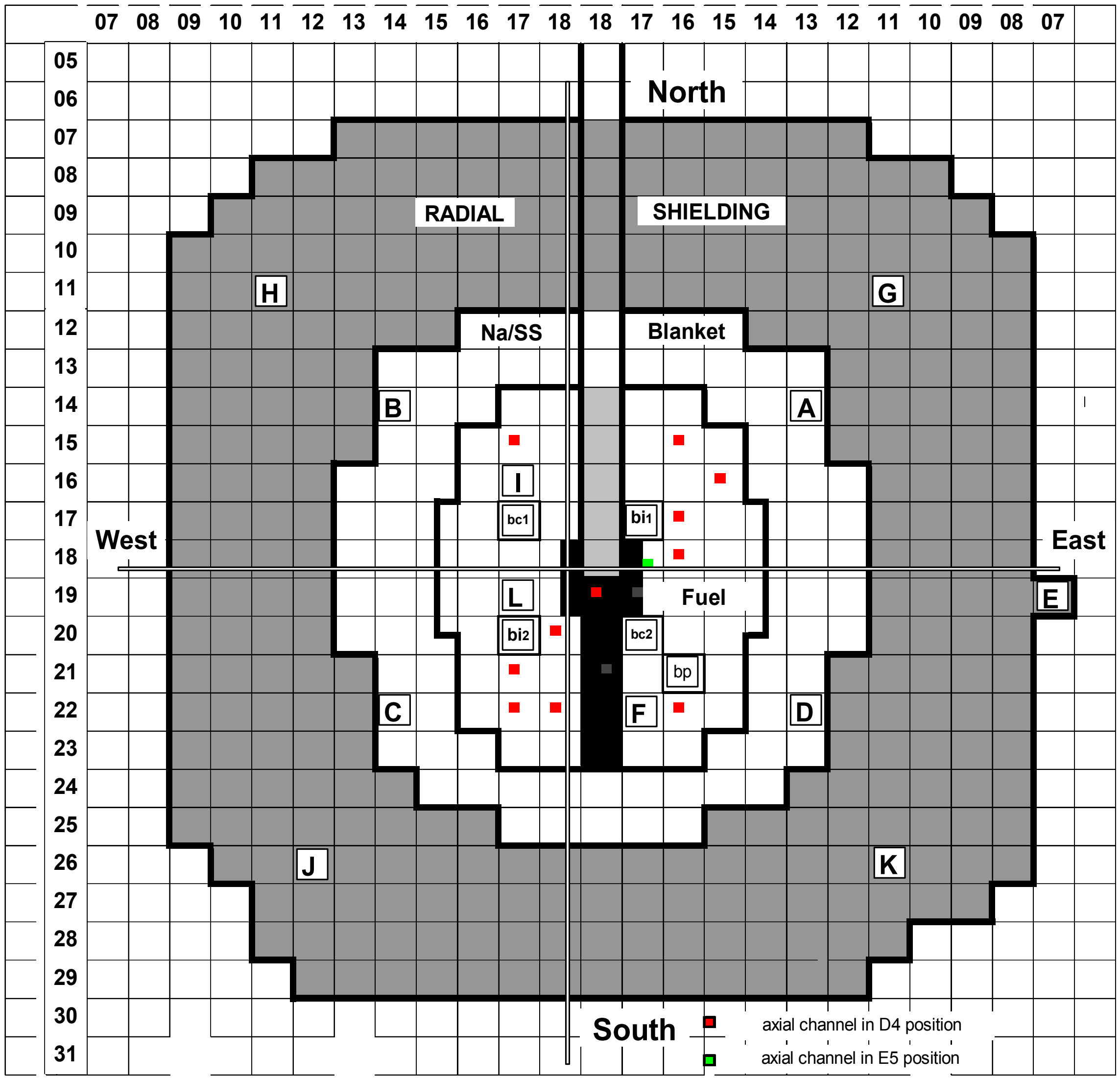
# AFCI ANL Physics Activities

- **Analysis, planning and support of coupling experiments (TRADE, MUSE)**
- **Analysis of irradiation experiments in power reactors (PROFIL)**
- **Uncertainty analysis for defining nuclear data needs for critical transmuters and ADS's**

# MUSE Program

- MUSE 4 first went critical in January 2001
- GENEPI (deuterium) deep subcritical June 2001
- GENEPI (deuterium) near critical November 2001-January 2002 (limited measurements)
- Reference core measurements through October 2002
- Transition to tritium target in November 2002
- Problems with filament of ion source causing delays
- Year 2003 planning
  - k=0.995, 0.97, 0.95
  - Pb, perhaps through 1st quarter of 2004
- Gas cooled configuration plans for 2004; US participation requested

# MUSE 4 Critical Configuration 01/09/2001



# Primary Measurements in MUSE

- **Sub-criticality**
  - **MSM (Modified Source Method)**
  - **Rod drop**
  - **Pulsed source**
  - **Feynman, Rossi $\alpha$**
- **Core characterization**
  - **source importance**
  - **$ß_{eff}$ /$\Lambda$**
  - **spectrum (passive with foils, and active with He-3 detector) and spectral indices**
  - **reaction rate profiles**

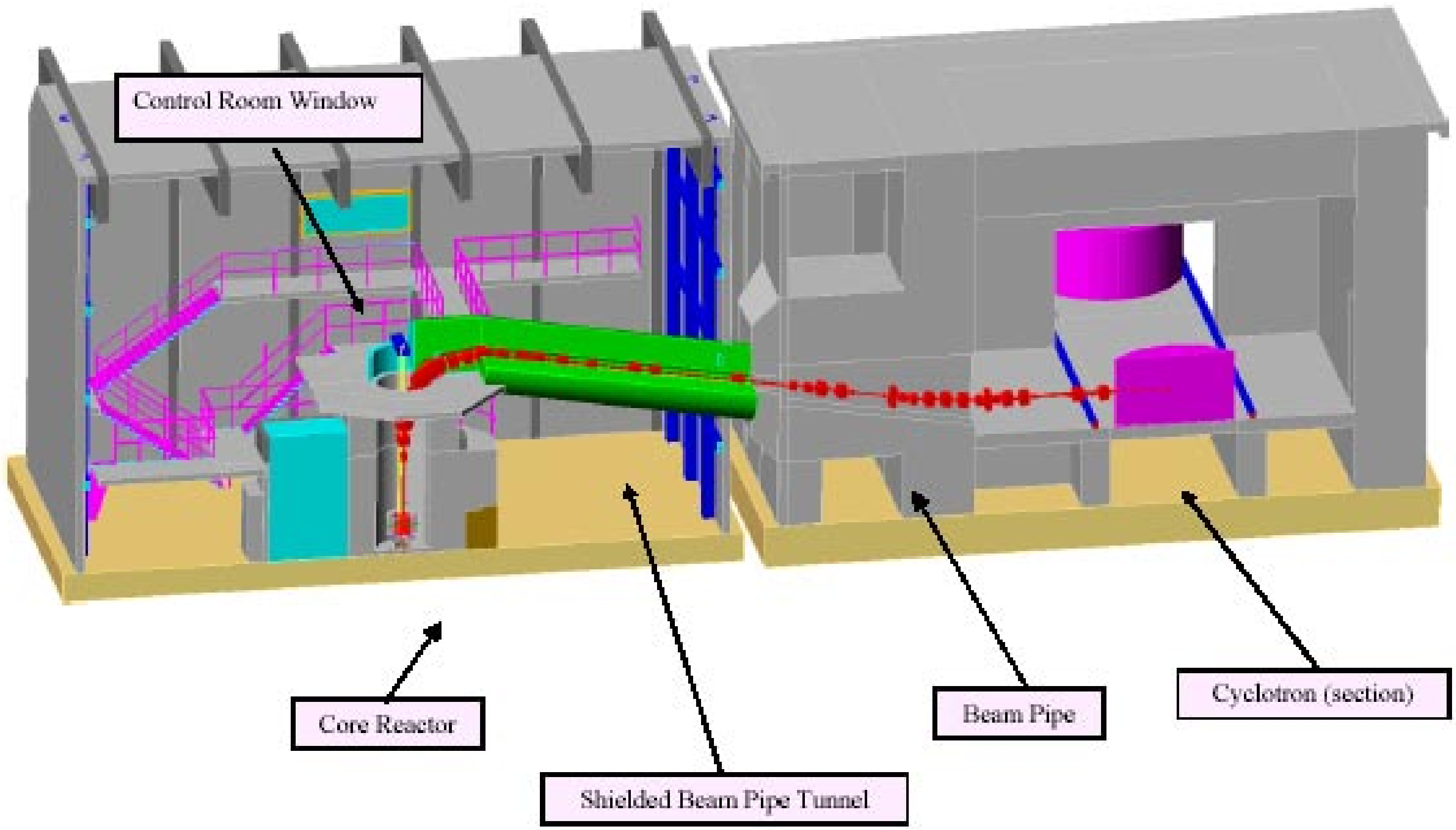
## Analysis of the MUSE 4 Configuration

- **A very important result has been achieved in the calculation of reaction rate distribution for configuration with reflector in direct contact with the core (no presence of blanket). The use of a very large number of groups (~1000) has allowed to accurately reproduce the spectrum transient and consequently dramatically improve the results. This solves a longstanding (more than a decade) discrepancy for these kinds of configurations.**
- **Following these findings an iterative methodology, based on conservation of reaction rates, has been successfully developed for allowing to reproduce the same type of reaction rate distributions obtained with the large of number of groups but, this time, using a broad (more reasonable) energy structure (33 groups). This methodology could be eventually incorporated in a cell code.**

# TRADE

- ENEA (Italy)
- Couple a TRIGA reactor with real spallation source (115 Mev cyclotron/heavy target)
- TRIGA has temperature feedback and poisoning effectc
- Next step after MUSE in a sequence of validation steps towards a real ADS
- TRADE has strong financial backing from ENEA and CEA, with high probability of EU funding

# TRADE LAYOUT



# TRADE Experiments

- Pre-TRADE characterizations Fall 2002
- TRADE Reference Core Spring 2003
- TRADE SC with DT source Summer 2003
- TRADE SC with cyclotron Summer 2006
- US involved in:
  - Accelerator review (LANL)
  - Target design (LANL)
  - Physics design (ANL)
  - Experimental lead (ANL)
  - Project scientific lead (MS-ANL)

# PROFIL-1 C/E and Uncertanties

| Data Type | C/E | | | Total Uncertainty | | |
|---|---|---|---|---|---|---|
| | JEF2.2 | ENDF/B-V | ENDF/B-VI | NEC | PEC | TEC |
| $\sigma_{capt}$ U-235 | 0.95 ± 1.7 % | 0.99 ± 1.7 % | 0.95 ± 1.7 % | **3.4 %** | **6.5 %** | **7.6 %** |
| $\sigma_{capt}$ U-238 | 0.98 ± 2.3 % | 1.02 ± 2.3 % | 0.98 ± 2.3 % | **1.7 %** | **2.2 %** | **3.1 %** |
| $\sigma_{capt}$ Pu-238 | 0.98 ± 4.0 % | 1.30 ± 4.0 % | 1.69 ± 4.0 % | **23.6 %** | **32.3 %** | **48.0 %** |
| $\sigma_{capt}$ Pu-239 | 0.99 ± 3.0 % | 0.96 ± 3.0 % | 0.94 ± 3.0 % | **5.8 %** | **7.2 %** | **10.6 %** |
| $\sigma_{capt}$ Pu-240 | 1.14 ± 2.2 % | 1.07 ± 2.2 % | 0.99 ± 2.2 % | **12.3 %** | **16.4 %** | **23.7 %** |
| $\sigma_{capt}$ Pu-241 | 1.24 ± 4.1 % | 1.03 ± 4.1 % | 0.88 ± 4.1 % | **14.2 %** | **21.1 %** | **27.4 %** |
| $\sigma_{capt}$ Pu-242 | 1.19 ± 3.5 % | 1.11 ± 3.5 % | 1.06 ± 3.5 % | **13.3 %** | **17.8 %** | **24.9 %** |
| $\sigma_{capt}$ Am-241 | 1.02 ± 1.7 % | 0.87 ± 1.7 % | 0.83 ± 1.7 % | **10.6 %** | **13.8 %** | **20.6 %** |

## TRANSMUTATION PHYSICS:
## THE RELEVANCE OF NUCLEAR DATA

- **Nuclear data uncertainty effects on key parameters**
- **Intermediate energy ($20 \leq E < 200$ MeV) data impact**
- **Target accuracies and feedback to data projects**
- **Role of integral and differential measurements**

## NUCLEAR DATA UNCERTAINTY EFFECTS ON:

- **Criticality (multiplication factor)**
- **Doppler Reactivity Coefficient**
- **Coolant Void Reactivity Coefficient**
- **Effective Delayed Neutron Fraction**
- **Reactivity Loss during Irradiation**
- **Transmutation Potential**
- **Peak Power Value**
- **$\varphi^*$ Parameter (for subcritical ADS systems)**
- **Max Dpa, Max He– and H- production, Max (He-production)/Dpa**
- **Decay Heat**

→ Use of GPT for sensitivity coefficient assessment

# Background

- The uncertainty analysis is applied to a transmutation dedicated core (MA : Pu = 2 : 1)
- Nuclear Data uncertainties: "JEF-2" covariance matrix applied to ENDF/B-VI data
- Hypothesis on correlations:
  - No correlation (in energy, among reactions etc)
  - Full energy correlation
  - Partial energy correlation (by energy "band")

## Main Parameters of the Reference System

| $K_{eff}$ | $\hat{\beta}_{eff}$ [pcm] | $\Delta\rho^{Doppler}$ (a) | $\Delta\rho^{void}$ | $\Delta\rho^{cycle}$ 1 year (b) | $\Delta\rho^{cycle}$ 2 years (b) | Decay Heat (d) | Peak Power |
|---|---|---|---|---|---|---|---|
| 0.948164 | 185.4 | -0.00026 | +0.02906 | -0.01196 | -0.02158 | 25 MWth | 2.9 |

$(\Delta n)^{cycle}$ (c) $[10^{24}$ at./cm$^3]$

| Pu238 | Am241 | Am242m | Am243 | Cm242 | Cm244 | Cm245 |
|---|---|---|---|---|---|---|
| 5.19E-5 | -8.64E-5 | 8.34E-6 | -5.24E-5 | 2.68E-5 | 2.28E-5 | 1.50E-6 |

(a) For $\Delta T = T - T_{Ref} = 1773K - 980K$;

(b) At full power;

(c) One year irradiation;

(d) At discharge. Nominal power of the core: 377MWth;

## Main Parameters of the Reference System

| $\varphi^*$ | Max Dpa [$sec^{-1} \times cm^{-3}$] | Max He-production [$sec^{-1} \times cm^{-3}$] | Max H-production [$sec^{-1} \times cm^{-3}$] | Max (He-production)/Dpa |
|---|---|---|---|---|
| 1.18 | 2.58E+16 | 6.15E+15 | 6.77E+16 | 0.24 |

# $\Delta\rho^{cycle}$ (1 year) – Perturbation Breakdown by Isotope (Values in pcm)

| Isotope | Capture | Fission | Elastic Removal | Inelastic + (n,xn) Removal | SUM |
|---|---|---|---|---|---|
| U234 | **-2.5** | **6.0** | **-** | **-0.9** | 2.6 |
| U235 | **-0.1** | **1.2** | **-** | **0** | 1.1 |
| U236 | **-0.1** | **0.1** | **-** | **0** | -0.1 |
| Np237 | **616.6** | **-659.9** | **-1.7** | **74.8** | 29.8 |
| Pu238 | **-264.5** | **3060.5** | **-** | **-55.4** | 2740.6 |
| Pu239 | **277.2** | **-5389.0** | **-2.2** | **82.2** | -5031.8 |
| Pu240 | **-28.6** | **108.6** | **0.8** | **-7.5** | 73.3 |
| Pu241 | **100.9** | **-2032.1** | **-0.9** | **19** | -1913.2 |
| Pu242 | **-43.2** | **139.5** | **0.6** | **-11.6** | 85.2 |
| Am241 | **1712.8** | **-1620.4** | **-2.6** | **127.3** | 217.0 |
| Am242m | **-39.3** | **1354.4** | **-0.2** | **-21** | 1293.9 |
| Am242f | **-1.1** | **29.3** | **-** | **-0.3** | 28.0 |
| Am243 | **870.9** | **-700.3** | **-0.9** | **199.1** | 368.8 |
| Cm242 | **-119.2** | **986.2** | **-0.1** | **-45.1** | 821.9 |
| Cm243 | **-0.1** | **14.1** | **-** | **-0.1** | 13.9 |
| Cm244 | **-135.6** | **735.6** | **-0.2** | **-36.6** | 563.1 |
| Cm245 | **-5.6** | **327.0** | **0.1** | **-2.4** | 319.1 |
| Cm246 | **-1.2** | **10.8** | **-** | **-0.7** | 8.8 |
| Cm247 | **-** | **1.3** | **-** | **0** | 1.3 |
| Fission Products | **-574** | **0** | **-41.1** | **-286.3** | -901.3 |
| SUM | 2363.2 | -3627.3 | -48.6 | 34.6 | -1278.2 |

## Isotope Breakdown of the Core Coolant Void Reactivity by Component (Values in pcm)

| | Capture | Fission | Leakage | Elastic Removal | Inelastic + (n,xn) Removal | SUM |
|---|---|---|---|---|---|---|
| Np237 | **0.3** | **10.1** | **-** | **0.1** | **0.9** | 11.3 |
| Pu238 | **-** | **1.1** | **-** | **-** | **-** | 1.1 |
| Pu239 | **3.8** | **-9.2** | **0.1** | **-** | **0.5** | -4.8 |
| Pu240 | **1.2** | **6.5** | **-** | **0.1** | **0.7** | 8.5 |
| Pu241 | **0.2** | **0.7** | **-** | **-** | **-** | 0.9 |
| Pu242 | **0.2** | **2.1** | **-** | **-** | **-** | 2.5 |
| Am241 | **4.3** | **34.9** | **0.1** | **-** | **1.4** | 40.7 |
| Am242m | **-** | **0.4** | **-** | **-** | **-** | 0.4 |
| Am243 | **3.1** | **17.9** | **-0.1** | **0.4** | **-3.7** | 17.6 |
| Cm242 | **-** | **-** | **-** | **-** | **-** | - |
| Cm243 | **-** | **0.1** | **-** | **-** | **-** | 0.1 |
| Cm244 | **2.6** | **8.9** | **-** | **0.2** | **0.3** | 11.9 |
| Cm245 | **-** | **0.4** | **-** | **-** | **0.1** | 0.5 |
| Zr | **23.8** | **-** | **-6.6** | **36.2** | **-16.3** | 37 |
| N15 | **-** | **-** | **-7.5** | **132.7** | **-** | 125.2 |
| Fe | **61** | **-** | **-79.1** | **121.3** | **4.6** | 107.9 |
| Cr | **3.9** | **-** | **-5.8** | **15.5** | **-5.7** | 7.9 |
| Ni | **-0.3** | **-** | **0.1** | **0.4** | **-0.2** | - |
| Mo | **-** | **-** | **-** | **0.3** | **-0.2** | - |
| Mn | **0.8** | **-** | **-** | **0.8** | **0.3** | 1.9 |
| W | **0.3** | **-** | **-** | **-** | **-** | 0.3 |
| Pb | **224.2** | **-** | **-1913.2** | **728.3** | **2229.5** | 1268.8 |
| Bi | **393.2** | **-** | **-2336.3** | **929.2** | **2561.4** | 1547.5 |
| SUM | 722.7 | 73.8 | -4348.3 | 1965.5 | 4773.7 | 3187.4 |

## Resulting Uncertainties (in Percentage) for the Integral Parameters of the Reference System

| | φ* | Max Dpa | Max He-production | Max H product. | Max (He-production)/Dpa |
|---|---|---|---|---|---|
| $\Delta I_{no\_correlation}$ | ±2.74 | ±29.9 | ±43.6 | ±28.5 | ±45.5 |
| $\Delta I_{PEC}$ [(a)] | ±5.07 | ±48.9 | ±59.1 | ±53.1 | ±67.4 |

[(a)] Partial correlation in energy

## Resulting Uncertainties (in Percentage) for the Integral Parameters of the Reference System

| | $K_{eff}$ | $\hat{\beta}_{eff}$ | $\Delta\rho^{void}$ | $\Delta\rho^{cycle}$ (1 year) | Peak Power |
|---|---|---|---|---|---|
| $\Delta I_{no\_correlation}$ | ±2.77 | ±11.3 | ±35.2 | ±47.4 | ±20.5 |
| $\Delta I_{PEC}$ [(a)] | ±4.41 | ±17.4 | ±59.3 | ±73.1 | ±32.4 |

| | $\Delta n^{cycle\ (b)}$ | | | | | | |
|---|---|---|---|---|---|---|---|
| | Pu238 | Am241 | Am242m | Am243 | Cm242 | Cm244 | Cm245 |
| $\Delta I_{no\_correlation}$ | ±7.3 | ±15.1 | ±15.9 | ±15.3 | ±12.5 | ±25.6 | ±81.2 |
| $\Delta I_{PEC}$ [(a)] | ±10.9 | ±23.8 | ±23.2 | ±24.3 | ±18.3 | ±37.8 | ±122.9 |

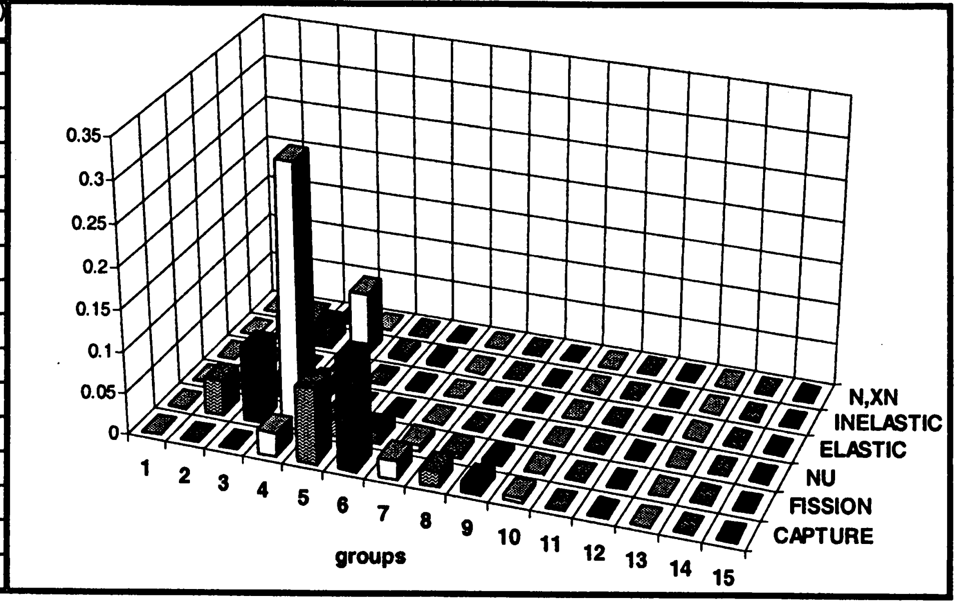
[(a)] Partial correlation in energy

[(b)] One year irradiation.

- **Significant impact of uncertainties:**
  - **MA data: $\sigma_f$, $\sigma_c$, $\sigma_{in}$ – Improvements needed**
  - **Some impact of intermediate energy data on parameters related e.g. to damage phenomena**
  - **Decay heat uncertainty mostly related to MA (e.g. Cm) data. Different contribution of MA and FP with respect to standard fuel reactors**
- **To establish priorities and target accuracies on data uncertainty reduction, a formal approach: define target accuracy on design parameter and find out required accuracy on data (the "inverse" problem)**

## $K_{eff}$ – Uncertainties (%) by Group – No Energy Correlation

| Gr. | [MeV][a] | $\sigma_{cap}$ | $\sigma_{fiss}$ | $\nu$ | $\sigma_{el}$ | $\sigma_{inel}$ | $\sigma_{n,2n}$ | Total[b] |
|---|---|---|---|---|---|---|---|---|
| 1 | 19.6 | 0.01 | 0.05 | 0.02 | - | 0.04 | 0.04 | 0.08 |
| 2 | 6.07 | 0.01 | 0.57 | 0.18 | 0.04 | 0.47 | - | 0.76 |
| 3 | 2.23 | 0.03 | 0.83 | 0.27 | 0.07 | 0.46 | - | 0.99 |
| 4 | 1.35 | 0.47 | 1.56 | 0.41 | 0.20 | 0.77 | - | 1.86 |
| 5 | 4.98e-1 | 0.84 | 0.39 | 0.08 | 0.10 | 0.19 | - | 0.95 |
| 6 | 1.83e-1 | 1.01 | 0.32 | 0.07 | 0.06 | 0.20 | - | 1.08 |
| 7 | 6.74e-2 | 0.41 | 0.24 | 0.07 | 0.02 | 0.04 | - | 0.49 |
| 8 | 2.48e-2 | 0.37 | 0.22 | 0.04 | 0.02 | 0.03 | - | 0.43 |
| 9 | 9.12e-3 | 0.31 | 0.20 | 0.03 | - | - | - | 0.37 |
| 10 | 2.04e-3 | 0.20 | 0.08 | 0.02 | - | - | - | 0.21 |
| 11 | 4.54e-4 | 0.04 | 0.01 | - | - | - | - | 0.04 |
| 12 | 2.26e-5 | - | - | - | - | - | - | - |
| 13 | 4.00e-6 | - | - | - | - | - | - | - |
| 14 | 5.40e-7 | - | - | - | - | - | - | - |
| 15 | 1.00e-7 | - | - | - | - | - | - | - |
| Total[b] | | 1.54 | 1.97 | 0.54 | 0.25 | 1.05 | 0.04 | 2.77 |

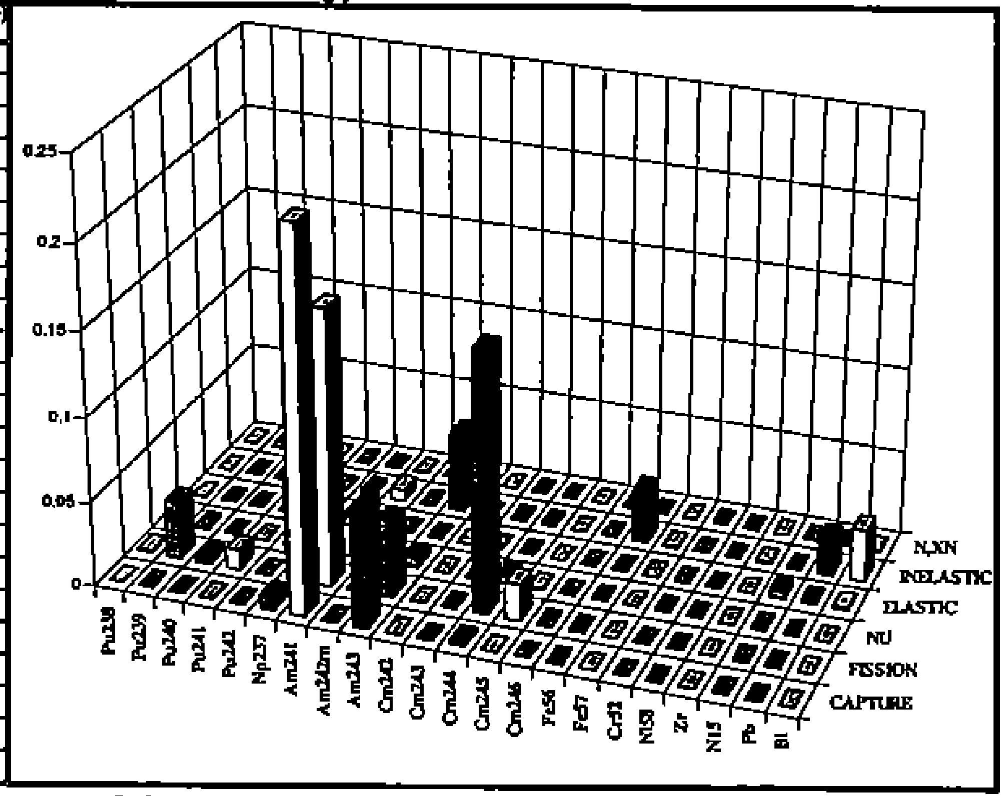



[a] High energy group boundary;

[b] Total obtained as the square root of the sum of the squares of individual contributions in row or column.

## $K_{eff}$ – Uncertainties (%) by Isotope – No Energy Correlation

| Isotope | $\sigma_{cap}$ | $\sigma_{fiss}$ | $\nu$ | $\sigma_{el}$ | $\sigma_{inel}$ | $\sigma_{n,2n}$ | Total[b] |
|---|---|---|---|---|---|---|---|
| Pu238 | 0.01 | 0.11 | 0.02 | - | - | - | 0.11 |
| Pu239 | 0.04 | 0.51 | 0.11 | - | 0.04 | - | 0.53 |
| Pu240 | 0.05 | 0.18 | 0.05 | - | 0.02 | - | 0.19 |
| Pu241 | 0.04 | 0.30 | 0.03 | - | 0.01 | - | 0.31 |
| Pu242 | 0.01 | 0.05 | 0.02 | - | 0.01 | - | 0.06 |
| Np237 | 0.24 | 0.70 | 0.21 | - | 0.14 | - | 0.78 |
| Am241 | 1.32 | 1.12 | 0.38 | - | 0.22 | - | 1.79 |
| Am242m | 0.01 | 0.09 | 0.03 | - | 0.01 | - | 0.10 |
| Am243 | 0.74 | 0.59 | 0.21 | - | 0.60 | - | 1.14 |
| Cm242 | - | - | - | - | - | - | - |
| Cm243 | - | 0.05 | 0.01 | - | - | - | 0.05 |
| Cm244 | 0.13 | 1.09 | 0.18 | - | 0.07 | - | 1.11 |
| Cm245 | 0.01 | 0.41 | 0.08 | - | 0.01 | - | 0.42 |
| Cm246 | - | - | - | - | - | - | - |
| Fe56 | 0.03 | - | - | 0.05 | 0.49 | - | 0.50 |
| Fe57 | - | - | - | - | 0.06 | - | 0.06 |
| Cr52 | 0.01 | - | - | 0.01 | 0.03 | - | 0.03 |
| Ni58 | - | - | - | - | - | - | - |
| Zr | 0.03 | - | - | 0.03 | 0.07 | - | 0.09 |
| N15 | - | - | - | 0.19 | 0.01 | - | 0.19 |
| Pb | 0.02 | - | - | 0.10 | 0.41 | 0.02 | 0.43 |
| Bi | 0.04 | - | - | 0.11 | 0.49 | 0.03 | 0.50 |
| Total[b] | 1.54 | 1.97 | 0.54 | 0.25 | 1.05 | 0.04 | 2.77 |



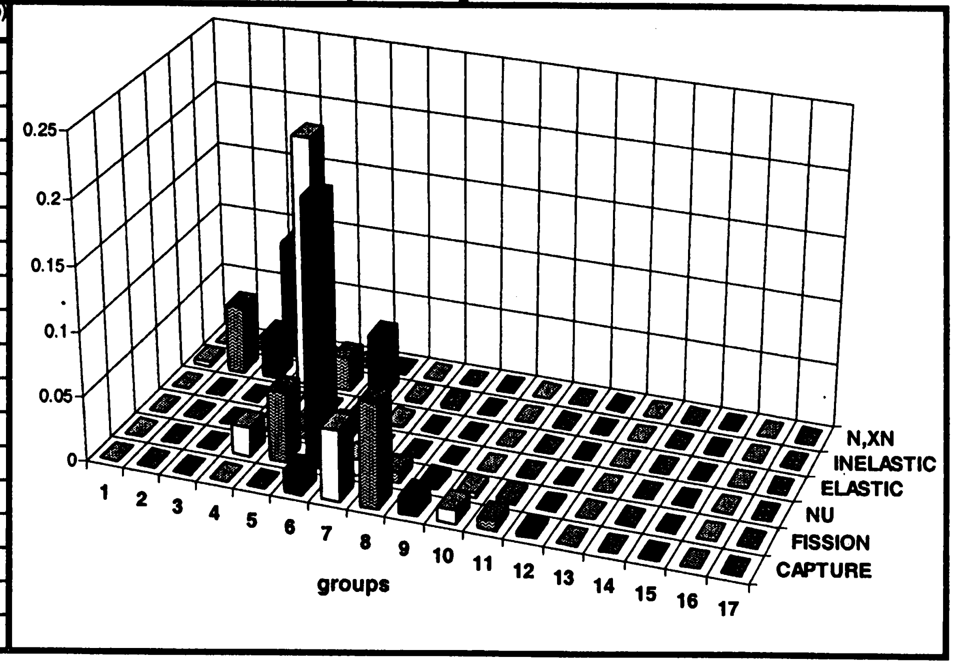

[b] Total obtained as the square root of the sum of the squares of individual contributions in row or column.

# Uncertainties on the Nuclear Density Variation of:
# Pu-238, Am-241, Am-242m, Am-243, Cm-242, Cm-244, Cm-245 (Values in Percentage)

| Isotope | Uncertainty due to: | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Pu238 | Np237 | | Pu238 | | Am241 | | Cm242 | | **7.33** |
| | **Capture** | **Fission** | **Capture** | **Fission** | **Capture** | **Fission** | **Capture** | **Fission** | |
| | **3.67** | **0.12** | **0.19** | **0.61** | **6.31** | **0.04** | **0.06** | **0.09** | |
| Am241 | Am241 | | | | | | | | **15.12** |
| | **Capture** | **Fission** | | | | | | | |
| | **11.06** | **10.31** | | | | | | | |
| Am242m | Am241 | | Am242m | | | | | | **15.91** |
| | **Capture** | **Fission** | **Capture** | **Fission** | | | | | |
| | **15.70** | **0.15** | **0.83** | **2.45** | | | | | |
| Am243 | Pu242 | Am243 | | | | | | | **15.28** |
| | **Capture** | **Capture** | **Fission** | | | | | | |
| | **0.22** | **10.66** | **10.94** | | | | | | |
| Cm242 | Am241 | | Cm242 | | | | | | **12.54** |
| | **Capture** | **Fission** | **Capture** | **Fission** | | | | | |
| | **12.54** | **0.15** | **0.17** | **0.27** | | | | | |
| Cm244 | Am243 | | Cm244 | | | | | | **25.55** |
| | **Capture** | **Fission** | **Capture** | **Fission** | **(n,2n)** | | | | |
| | **23.48** | **0.20** | **4.98** | **8.75** | **0.20** | | | | |
| Cm245 | Am243 | | Cm244 | | | Cm245 | | | **81.19** |
| | **Capture** | **Fission** | **Capture** | **Fission** | **(n,2n)** | **Capture** | **Fission** | **(n,2n)** | |
| | **4.82** | **0.03** | **72.33** | **1.71** | **0.04** | **5.48** | **36.10** | **0.03** | |

## Max (He-production)/Dpa – Uncertainties (%) by Group

| Gr. | [MeV] [a] | $\sigma_{cap}$ | $\sigma_{fiss}$ | $\nu$ | $\sigma_{el}$ | $\sigma_{inel}$ | $\sigma_{n,2n}$ | Total [b] |
|---|---|---|---|---|---|---|---|---|
| 1 | 150 | - | - | - | 0.1 | 4.8 | - | 4.8 |
| 2 | 55.2 | - | 0.1 | - | 0.2 | 20.1 | 6.4 | 21.1 |
| 3 | 19.6 | - | 0.7 | 0.2 | 0.7 | 11.6 | 34.0 | 35.9 |
| 4 | 6.07 | 0.1 | 3.2 | 1.0 | 0.3 | 4.5 | - | 5.6 |
| 5 | 2.23 | 0.2 | 4.7 | 1.6 | 0.5 | 4.3 | - | 6.6 |
| 6 | 1.35 | 3.1 | 9.2 | 2.5 | 1.5 | 5.8 | - | 11.7 |
| 7 | 4.98e-1 | 5.2 | 2.4 | 0.5 | 0.8 | 1.3 | - | 6.0 |
| 8 | 1.83e-1 | 6.3 | 2.0 | 0.4 | 0.5 | 1.2 | - | 6.7 |
| 9 | 6.74e-2 | 2.6 | 1.5 | 0.4 | 0.2 | 0.2 | - | 3.0 |
| 10 | 2.48e-2 | 2.2 | 1.3 | 0.2 | 0.2 | 0.1 | - | 2.6 |
| 11 | 9.12e-3 | 1.9 | 1.2 | 0.2 | - | - | - | 2.3 |
| 12 | 2.04e-3 | 1.2 | 0.5 | 0.1 | - | - | - | 1.3 |
| 13 | 4.54e-4 | 0.2 | 0.1 | - | - | - | - | 0.2 |
| 14 | 2.26e-5 | - | - | - | - | - | - | - |
| 15 | 4.00e-6 | - | - | - | - | - | - | - |
| 16 | 5.40e-7 | - | - | - | - | - | - | - |
| 17 | 1.00e-7 | - | - | - | - | - | - | - |
| Total [b] | | 9.6 | 11.5 | 3.2 | 2.0 | 14.1 | 40.4 | 45.5 |




[a] High energy group boundary;
[b] Total obtained as the square root of the sum of the squares of individual contributions in row or column.

## Decay Heat - Relative Contribution (in Percentage) of Heavy Isotopes and Fission Products, at Different Cooling Times.

| Dedicated System | **Discharge** [1] | **500 sec** | **1000 sec** | **3000 sec** | **1 hour** | **12 hours** | **1 day** | **10 days** |
|---|---|---|---|---|---|---|---|---|
| **Heavy Elements** | **23** | **46** | **50** | **57** | **58** | **74** | **77** | **86** |
| **Fission Products** | **77** | **53** | **50** | **43** | **41** | **26** | **22** | **14** |
| SUPERPHENIX | **Discharge** [1] | **500 sec** | **1000 sec** | **3000 sec** | **1 hour** | **12 hours** | **1 day** | **10 days** |
| **Heavy Elements** | **8.1** | | **18.9** | **19.0** | **19.0** | **25.8** | **26.7** | **4.61** |
| **Fission Products** | **89.7** | | **74.6** | **72.6** | **72.3** | **63.7** | **62.1** | **73.2** |

[1] EOL (2 years)

## Decay Heat [Watts] and its Evolution in Time

| | Discharge[1] | 500 sec | 1000 sec | 3000 sec | 1 hour | 12 hours | 1 day | 10 days |
|---|---|---|---|---|---|---|---|---|
| Light Elements | 6.98E+4 | 5.72E+4 | 5.46E+4 | 5.24E+4 | 5.19E+4 | 4.21E+4 | 4.14E+4 | 3.89E+4 |
| Heavy Elements | 5.64E+6 | 5.51E+6 | 5.40E+6 | 5.14E+6 | 5.09E+6 | 4.85E+6 | 4.77E+6 | 4.38E+6 |
| Fission Products | 1.93E+7 | 6.36E+6 | 5.39E+6 | 3.84E+6 | 3.61E+6 | 1.70E+6 | 1.39E+6 | 6.93E+5 |
| Total | 2.51E+7 | 1.19E+7 | 1.08E+7 | 9.03E+6 | 8.76E+6 | 6.59E+6 | 6.20E+6 | 5.11E+6 |

[1] EOL (2 years)

## Decay Heat [Watts] – Heavy Element Breakdown by Isotope

| | Discharge[1] | 500 sec | 1000 sec | 3000 sec | 1 hour | 12 hours | 1 day | 10 days |
|---|---|---|---|---|---|---|---|---|
| U | 7.63E+0 | 7.62E+0 | 7.61E+0 | 7.59E+0 | 7.58E+0 | 7.29E+0 | 7.01E+0 | 3.71E+0 |
| Np | 3.05E+5 | 3.04E+5 | 3.04E+5 | 3.01E+5 | 3.01E+5 | 2.58E+5 | 2.19E+5 | 1.15E+4 |
| Pu | 9.59E+4 | 9.58E+4 | 9.56E+4 | 9.50E+4 | 9.49E+4 | 8.93E+4 | 8.81E+4 | 8.85E+4 |
| Am | 9.08E+5 | 7.73E+5 | 6.65E+5 | 4.08E+5 | 3.66E+5 | 1.73E+5 | 1.34E+5 | 7.83E+4 |
| Cm | 4.33E+6 | 4.33E+6 | 4.33E+6 | 4.33E+6 | 4.33E+6 | 4.33E+6 | 4.33E+6 | 4.20E+6 |
| Bk | 1.37E-3 | 1.35E-3 | 1.33E-3 | 1.26E-3 | 1.24E-3 | 7.09E-4 | 6.58E-4 | 6.41E-4 |
| Cf | 2.16E-4 | 2.16E-4 | 2.16E-4 | 2.16E-4 | 2.16E-4 | 2.17E-4 | 2.17E-4 | 2.22E-4 |
| Total | 5.64E+6 | 5.51E+6 | 5.40E+6 | 5.14E+6 | 5.09E+6 | 4.85E+6 | 4.77E+6 | 4.38E+6 |

[1] EOL (2 years)

## Selected Integral Parameters: Uncertainty due to all Data Uncertainties ($\Delta I_{initial}$); Target Accuracies ($\Delta I_{required}$); Resulting Uncertainty from a Minimization Procedure ($\Delta I_{resulting}$).

| | $K_{eff}$ | φ* | Power Peak | Max Dpa | Max He-production | Max H-production. | Max He-prod./Dpa |
|---|---|---|---|---|---|---|---|
| $\Delta I_{initial}$ | ±2.77 | ±2.74 | ±20.50 | ±29.90 | ±43.60 | ±28.50 | ±45.50 |
| $\Delta I_{required}$ | ±1% | ±2% | ±5% | ±15% | ±15% | ±15% | ±15% |
| $\Delta I_{resulting}$ | ±1.1% | ±1.0% | ±8.2% | ±13.0% | ±14.8% | ±13.7% | ±15.3% |

Cross-Sections Uncertainties for Selected Cross-Sections: Original Uncertainty and Required Uncertainty to Meet Integral Parameter Target Accuracy

| Isotope | Cross Section | Gr. | Original Uncert. (%) | Required Accuracy (%) |
|---|---|---|---|---|
| Pu239 | $\sigma_{fiss}$ | 4 | 6.5 | 3.4 |
| | | 5 | 4 | 3.1 |
| Pu241 | $\sigma_{fiss}$ | 6 | 10 | 5.6 |
| Np237 | $\sigma_{fiss}$ | 3 | 25 | 8.0 |
| | | 4 | 25 | 5.1 |
| | $\nu$ | 4 | 5 | 4.1 |
| Am241 | $\sigma_{cap}$ | 4 | 40 | 7.5 |
| | | 5 | 40 | 5.5 |
| | | 6 | 40 | 5.1 |
| | | 7 | 20 | 5.9 |
| | | 8 | 20 | 6.3 |
| | | 9 | 20 | 6.9 |
| | $\sigma_{fiss}$ | 2 | 20 | 5.6 |
| | | 3 | 20 | 4.6 |
| | | 4 | 20 | 3.9 |
| | $\nu$ | 3 | 5 | 3.8 |
| | | 4 | 5 | 3.3 |
| Am243 | $\sigma_{cap}$ | 4 | 40 | 10.4 |
| | | 5 | 40 | 5.5 |
| | | 6 | 40 | 5.1 |
| | | 7 | 20 | 5.9 |
| | | 8 | 20 | 6.3 |
| | $\sigma_{fiss}$ | 2 | 20 | 7.6 |
| | | 3 | 20 | 6.2 |
| | | 4 | 20 | 5.4 |
| | $\sigma_{inel}$ | 3 | 50 | 12.6 |
| | | 4 | 50 | 7.6 |
| | | 5 | 50 | 12.0 |
| | | 6 | 50 | 12.2 |

| Isotope | Cross Section | Gr.[a] | Original Uncert. (%) | Required Accuracy (%) |
|---|---|---|---|---|
| Cm244 | $\sigma_{fiss}$ | 2 | 40 | 10.0 |
| | | 3 | 40 | 8.5 |
| | | 4 | 40 | 5.0 |
| Cm245 | $\sigma_{fiss}$ | 5 | 30 | 9.7 |
| | | 6 | 30 | 9.6 |
| Fe56 | $\sigma_{inel}$ | 4 | 20 | 4.9 |
| N15 | $\sigma_{el}$ | 4 | 5 | 3.9 |
| Pb | $\sigma_{inel}$ | 1 | 40 | 20.4 |
| | | 2 | 40 | 9.8 |
| | | 3 | 40 | 10.6 |
| | | 4 | 40 | 10.1 |
| | $\sigma_{n,2n}$ | 1 | 100 | 21.5 |
| Bi | $\sigma_{inel}$ | 1 | 40 | 18.8 |
| | | 2 | 40 | 8.1 |
| | | 3 | 40 | 9.3 |
| | | 4 | 40 | 14.0 |
| | $\sigma_{n,2n}$ | 1 | 100 | 17.5 |
| $\sigma_{dpa}$ | | 1 | 20 | 20.0 |
| | | 2 | 20 | 12.0 |
| | | 3 | 20 | 12.1 |
| | | 4 | 20 | 8.8 |
| | | 5 | 20 | 20.0 |
| | | 6 | 20 | 20.0 |
| | | 7 | 20 | 10.9 |
| $\sigma_{(n,\alpha)}$ | | 1 | 20 | 10.8 |
| | | 2 | 20 | 20.0 |
| $\sigma_{(n,p)}$ | | 1 | 20 | 15.1 |
| | | 2 | 20 | 12.4 |
| | | 3 | 20 | 20.0 |

# Conclusions

- For “transmuter” reactors, data uncertainty reductions are mandatory, when preconceptual design studies would be required. Most needs appear below 20 MeV.
- Below 20 MeV, new evaluations and integral experiments (e.g. separated, pure isotope sample irradiation in power reactors, or AMS techniques) can provide most of the data needed. Some differential measurements (e.g. inelastic reactions) can be needed, together with few selected experiments in the resonance region.
- At high energy, (n,p) and (n,α) reaction measurements for structural materials should be given priority.
- These conclusions will be integrated with, and will give guidance to, the international nuclear data community.